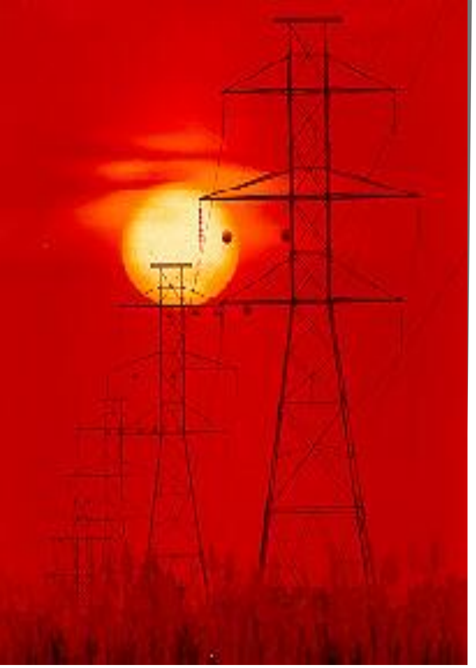

Overview of Smart Inverter Capabilities and Phased Approach

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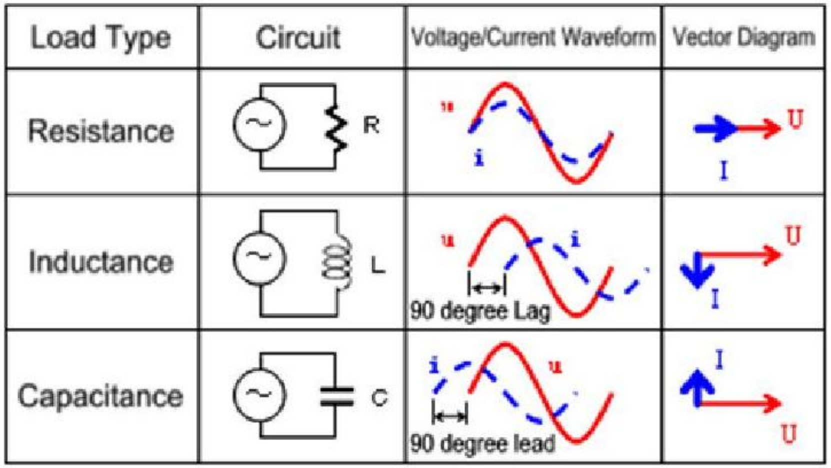
Power Systems 101: Voltage, Current, Watts, and Frequency

- Power systems are based on just a few electrical concepts:
  - **Voltage** is the "pushing" force that moves electricity
  - **Current** is the flow of electricity
  - **Watts** (**real power**) measures the electrical energy that results from voltage pushing current through loads
- In **Alternating Current (AC)** systems, like the power grid, both voltage and current swing back and forth, with a **Frequency of 60** times per second
  - Think of a child swinging back and forth

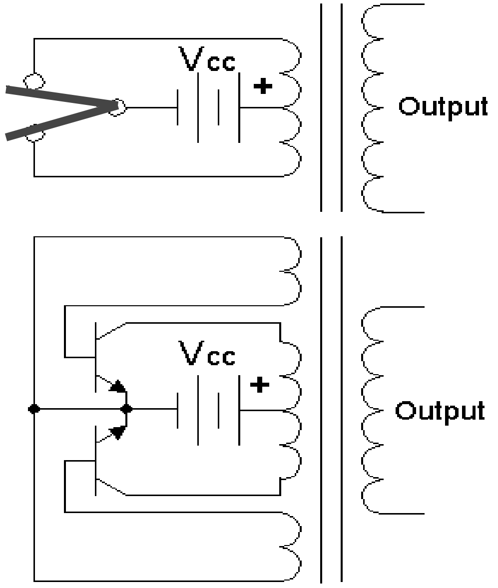
Voltage and Current Phases

- Voltage and current swings are affected by different types of loads
  - Voltage and current can be in synch (**in-phase**)
  - Voltage can lead in front of the current (leading **out-of-phase)**
  - Voltage can lag behind the current (lagging **out-of-phase)**
- Out-of-phase is inefficient
  - Think of pushing a child on a swing either before or after the peak of the swing – the swing slows down
- **Vars (reactive power)** measures how much out-of-phase voltage and current are

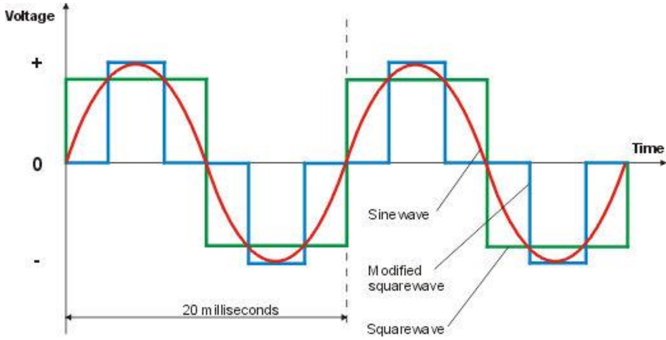


Overview of Inverter Technology – 101

- An inverter is an electrical power converter that changes ***direct current (DC)*** to ***alternating current (AC)***
  - Photovoltaic systems generate DC power
  - Inverters convert this DC power to AC power so these systems can interconnect with the grid

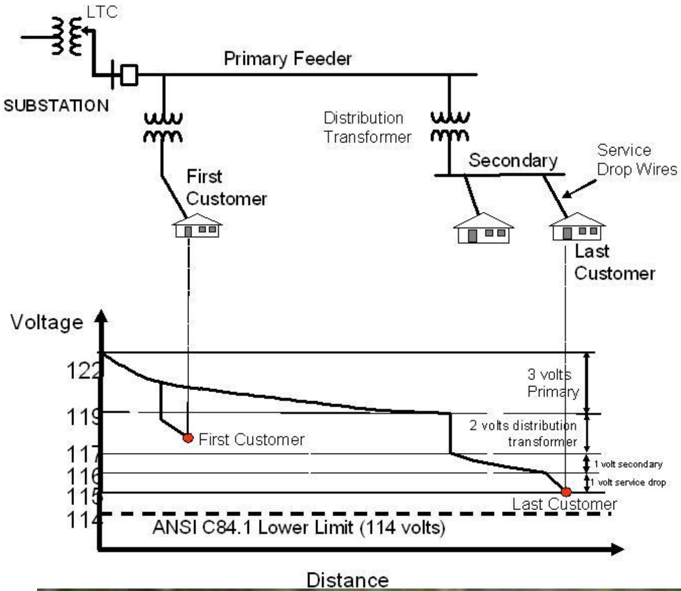


- Older inverters used switches that rapidly flipped back and forth, making a square wave
- **Modern inverters use software-driven electronics** to flip and smooth the output into standard 60 Hz waves



What Do Distribution Systems Need to Manage?

- **Voltage drops** on a power line as you move farther away from the substation
  - The end of a distribution power line can have very low voltage
- Air conditioners and other motors cause **lagging voltage**
  - Increasing vars is wasted energy
- **Brief short-circuits cause outages**
  - On windy days, lines can swing into each other
  - In Guam, snakes cause outages
  - In California, squirrels cause outages



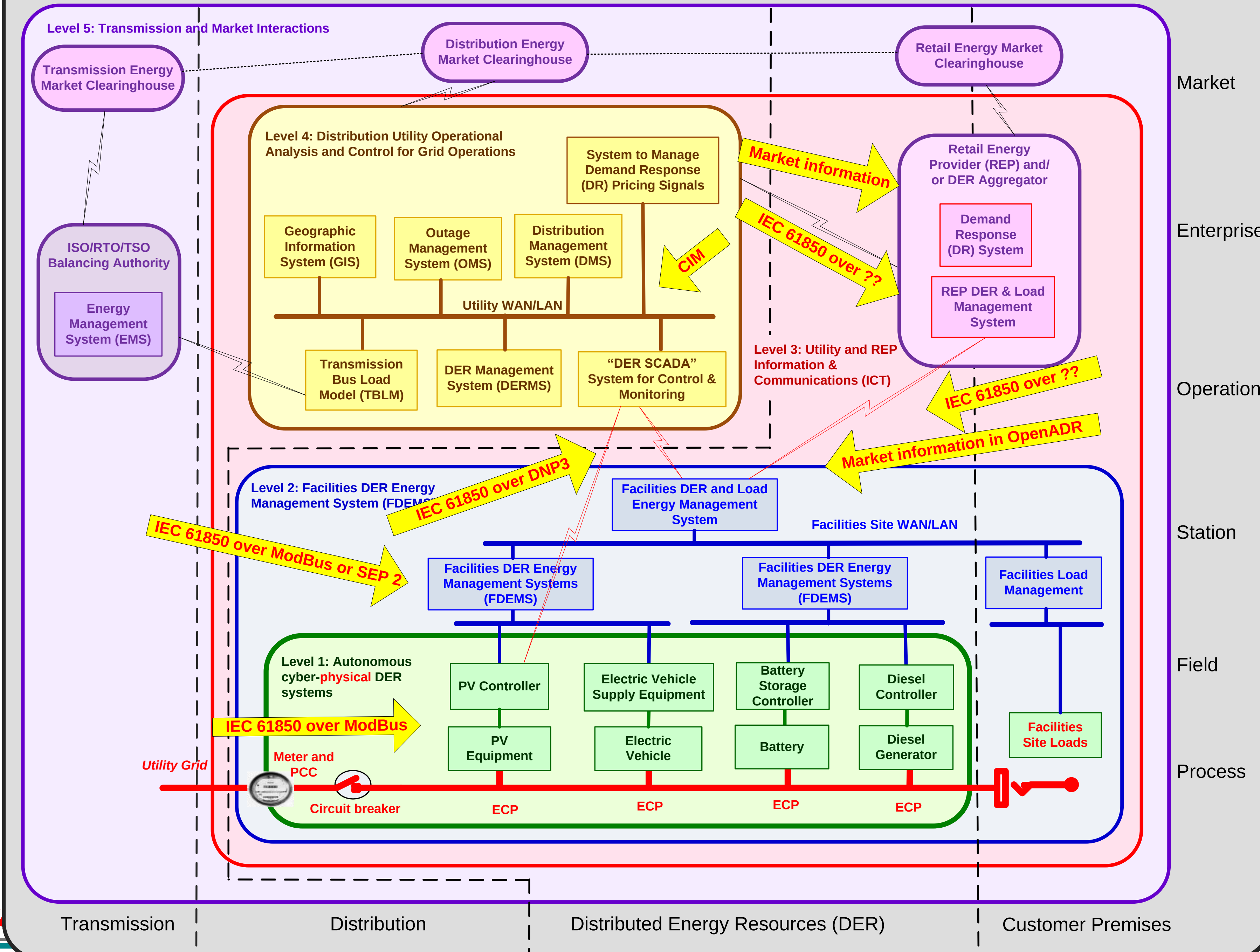
Smart Inverters – Helping to Manage the Distribution System

- Smart inverters can use their software-driven electronics to:
  - **Ride-through** wide ranges of voltage or frequency anomalies to improve resiliency and avoid unnecessary outages
  - **Respond to emergency commands** to improve reliability
  - **Counteract excess vars** by shifting the voltage-current phase
  - **Counteract voltage spikes and sags** to improve quality of service
  - **Counteract frequency deviations** to smooth frequency changes
  - **Respond to demand response pricing signals** to improve efficiency

Hierarchical Architecture of DER Systems

- How can utilities coordinate thousands or millions of DER systems, located at customer sites and owned by non-utilities?
  - Most DER systems must operate **autonomously** most of the time
    - Based on pre-established settings to meet utility requirements
    - Taking into account the DER owner preferences
  - **Communications** with utilities are required for:
    - Emergency situations
    - Market signals for demand response
    - Updating the DER settings used for autonomous operation
  - **DER systems are hierarchical**, so utility communications
    - May be direct (utility-owned or very large DER systems)
    - Most likely will be through a "Facility Energy Management System"
    - Can be through a Retail Energy Provider or Aggregator

Hierarchical DER System Five-Level Architecture, in SGAM Format



Why Does California Need These DER Functions?

- California Governor Brown has called for the **implementation of 12,000 MW** of "localized electricity generation", namely DER, which can help the State reach its goal to acquire 33 percent of its energy from eligible renewable energy resources by 2020.
- However, **high penetrations of these DER systems**, located within distribution grids which were designed only for handling customer loads, **could adversely affect California utility operations.**
- **European experience** with high penetrations of DER has shown that the implementation of some DER functions can cost-effectively **improve the reliability and efficiency** of the power grid.
  - ***Waiting to implement these functions may lead to costly upgrades and replacements – which actually occurred in Germany!***

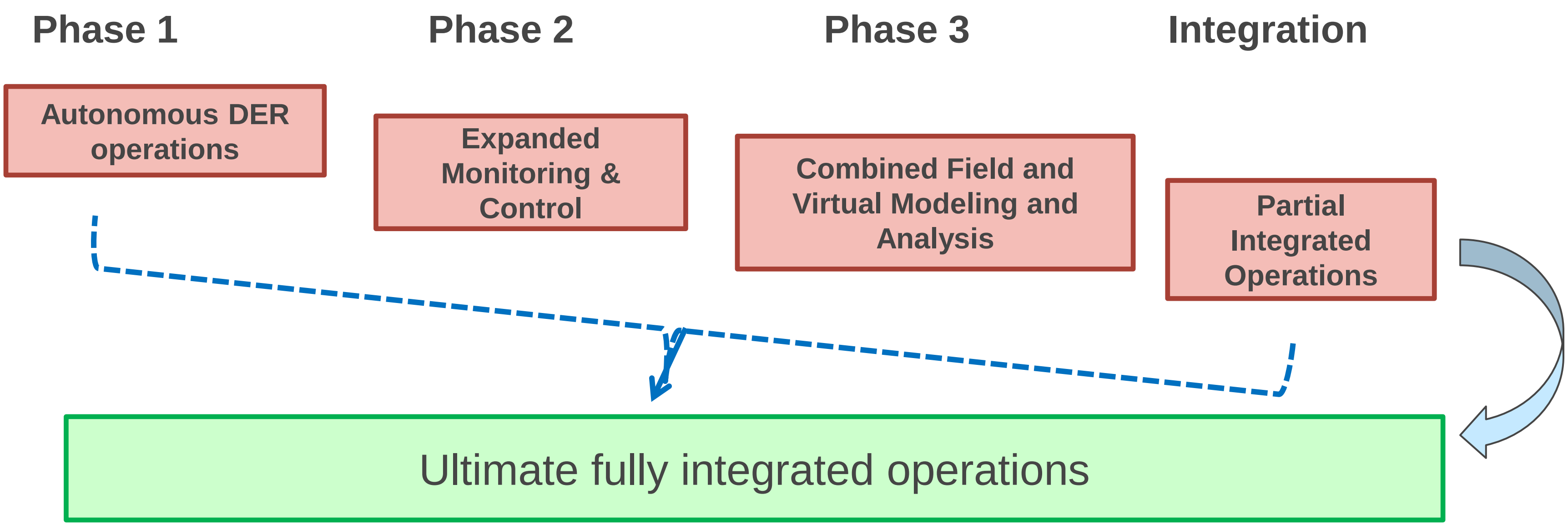
Status of Rule 21, IEEE 1547, and UL 1741

- **Rule 21** is largely based on **IEEE 1547 Standard** for Interconnecting Distributed Resources with Electric Power Systems, which was developed for low penetrations of DER:
  - IEEE 1547 prohibits DER systems from actively regulating the voltage at the Point of Common Coupling (the interconnection to the grid)
  - IEEE 1547 limits the voltage “ride-through” range
  - IEEE 1547 limits the frequency “ride-through” range
- IEEE 1547 is rapidly being “updated” to **IEEE 1547a** where these limitations are being revised to allow (but not mandate) more flexibility:
  - IEEE 1547a may be published by the end of this year
  - **IEEE 1547.1a** (testing) also needs to be updated
  - **UL 1741** safety requirements need to cover these new functions

California Response

- In California, the expectation of high penetrations of DER and the European experience with high penetrations have caused the utilities to actively pursue smart inverter functions
- The **CEC** initiated a joint effort with the **CPUC** to update Rule 21 to provide a consistent set of mandated and recommended DER functions
  - Initiated the "Smart Inverter" project in January 2013
  - Used experiences from the California utilities and the Europeans, as well as certain international standards
  - Discussed which DER functions should be mandated in bi-weekly meetings
  - **Developed recommendations for a phased approach** for Rule 21 mandates for DER functions

Phased Approach for Reaching the Ultimate Integration of DER Systems with Utility Operations



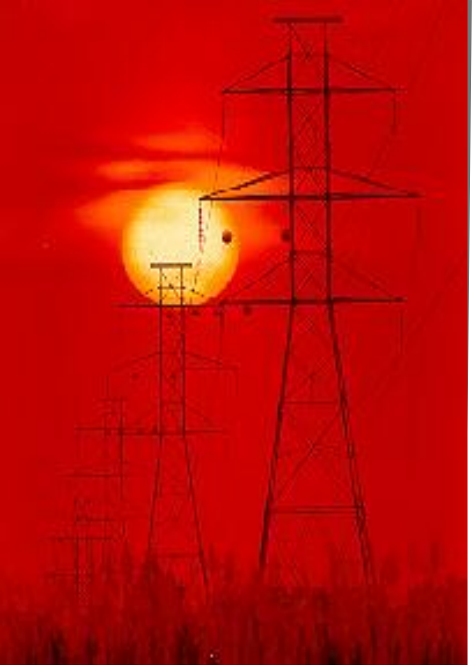
Phases:

1) Start with autonomous DER systems which provide volt/var management, low/high voltage ride-through, responses to frequency anomalies, etc. Use interconnection agreements to ensure appropriate autonomous settings.

2) Expand to situational awareness with hierarchical communication networks, monitoring aggregated smaller DER and direct monitoring of larger DER. Issue broadcast requests (pricing signal and/or tariff-based) and/or direct commands

3) Combine field and virtual modeling through power flow-based analysis, state estimation, contingency analysis, and other analysis applications to assess economics and reliability.

4) Ultimately integrate DER management with distribution automation, load management, and demand response for optimal power system management.



(Quick) Questions?